SINGLE PHASE PRESSURE PULSE SUMMARY

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Until recently, the objective of the 1Ø relief system for the Doubler dipoles has been to limit the 1Ø pressure pulse during a quench to approximately 100 psia. This pressure limit was chosen because the 1Ø bellow laminations deformed and the .049" quaded bore tubes installed in the 22' dipoles imploded at a static pressure of 150 psia.

The 1Ø relief system now installed at B12 (MK2 Kautzky valves venting into 8" header via flex hoses) previously limited the pressure pulse during a 4.0kA quench, in 22' dipoles at B12, to approximately 117 psia (ΔP = 92 psi, quiescent operating point 25 psia). The pressure pulse measured on 21' dipoles now installed at B12 is significantly higher (Fig. 1A). The first 3kA quench taken at a 40 psig valve threshold resulted in a pressure ΔP of 75 psi which extrapolates to a ΔP of 133 psi (P_{max} = 158 psia) at 4kA if an I^2 pressure dependance is assumed.

In an effort to reduce this pressure, all subsequent quenches were performed with the Kautzky relief valve threshold reduced from 40 to 25-30 psig. Although inadequate, this change allowed quenches up to 3.5kA ($88 \leq \Delta P \leq 100$ psi, $113 \leq P_{max} \leq 125$ psia). Removal of the stainless steel flex hose so that the relief valve vented to atmosphere had no noticeable effect on the 1Ø pressure pulse. The time development of the 1Ø pressure and the 8" header pressure measured at two locations is shown in Fig. 1B for a 4.1kA quench.

Although the mechanism for the higher pressure pulse in 21' magnets has not been established, it appears that it is related to the integral $\int I^2 dt$ (MIITS). While constrained in the Doubler power and quench protection system, the 21' dipoles now installed at B12 quench at 3.5kA with 4.0 MIITS (Fig. 2). The 22' dipoles used to quench at 3.5kA with approximately 5.0 MIITS. This indicates that the normal zone resistance now increases faster than in the past. The corresponding higher rate of magnetic energy transfer into heat should result in a higher He pressure. A change in the copper purity of the superconducting cable, the heater geometry, or heater energy are possible explanations for the increased quench resistance growth rate. The correlation of pressure pulse to MIITS during a quench were verified during a test conducted at MTF on June 19, 1981 (Fig. 3).

Proceeding on the assumption that it is too late to further modify the cryostat vent tubes, our options for reducing the pressure pulse are:

1. Modify the Kautzky valve and the plumbing downstream of this valve.
2. Control the MIITS during a quench.
3. Investigate the possibility of operating the cryostat at a higher pulsed pressure.

The first option has been extensively investigated at MTF. The following changes had no measurable effect on the 1Ø pressure pulse:

1. Removal of the flex hose and venting the Kautzky valve into atmosphere.
2. Increasing the Kautzky valve Venturi ID from approximately 0.9" to 1.0".

continued

3. Modifying the 90° miter bend in the Kautzky valve to a smooth elbow (Jöstlein modification).
4. Removal of the Kautzky control pressure at the instant of quench detection with a solenoid valve.

Reducing the control pressure on the Kautzky valves from 40 psig to 25 psig does reduce the pressure pulse and the lower control pressure has been adopted at B12. This requires that the control pressure be increased after a quench to insure reliable seating of the valves.

An experiment was conducted to determine what reduction in the pressure pulse one can expect by optimizing the 1Ø vent plumbing outside the magnet. A 2.0" ball valve was substituted for the Kautzky relief valve. With the ball valve open, the venting geometry outside the cryostat approximated an 18-3/4" long straight pipe whose ID increased from 1¼" to 2" in two steps and then vented into atmosphere. A microswitch mounted on the ball valve handle triggered the quench when the valve was fully open. At 4kA, this geometry reduced the pressure pulse by 23% (Fig. 4). In all probability, a cost effective geometry that equals this pressure reduction and collects the He in the 8" header will not be found.

The second option of reducing the pressure pulse by controlling the MIITS during a quench has also been explored. With our present heater geometry, it takes E>500 Joules into the heater to quench a dipole reliably at 1kA, $E \geq 250$ Joules at 4kA. From Fig. 3 it appears that we can reduce the 4kA pressure pulse by ≃20% at the cost of a heater supply which is programmed as a function of magnet current during the ramp. However, the data in Table I and quench No. 6 in Fig. 3 indicate that the MIITS during a quench are affected by factors other than the heater energy and quench current. Therefore, this method cannot be expected to guarantee a lower pressure pulse under every circumstance.

The third option; i.e., operating the cryostat at a higher pressure without major (any?) modification of the 1Ø relief system, has been adopted at B12. The magnets have been repeatedly quenched at 4kA without any indication of cryostat failure. The maximum 1Ø pressure pulse measured to date was 125 psi (ΔP) when the upper and lower magnet strings quenched within .13 sec of each other at 4kA. The peak pressure in the 8" header during this quench was 75 psig.

During one 3.5kA quench, the Kautzky valve on the dipole exactly centered between two spool pieces failed to open. The 1Ø pressure pulse measured during this valve failure was 120 psi (ΔP) as compared with 95±5 psi when all valves opened. This indicates that at least one 1Ø relief valve per magnet half-cell can malfunction without rupturing the cryostat.

The justification for operating the system at a pulsed pressure of approximately 150 psia is as follows:

continued

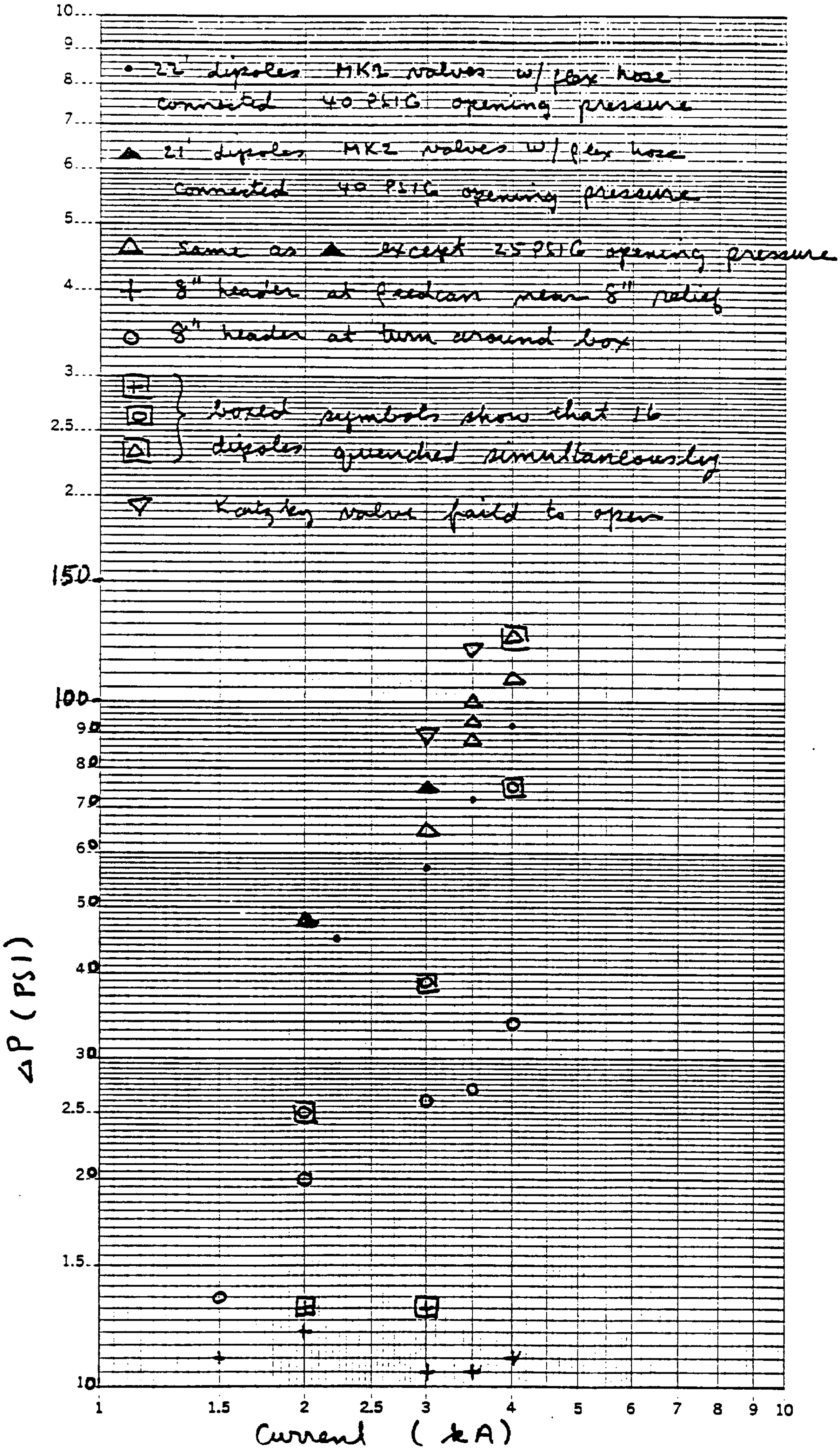

• 22 dipoles MK2 valves w/flex hose connected 40 PSIG opening pressure
▲ 21 dipoles MK2 valves w/flex hose connected 40 PSIG opening pressure
△ Same as ▲ except 25 PSIG opening pressure
+ 8" header at feedcan near 8" relief
○ 8" header at turn around box
boxed symbols show that 16 dipoles quenched simultaneously
▽ Kautzky valve failed to open
ΔP (PSI)
Current (kA)

FIG. 1A

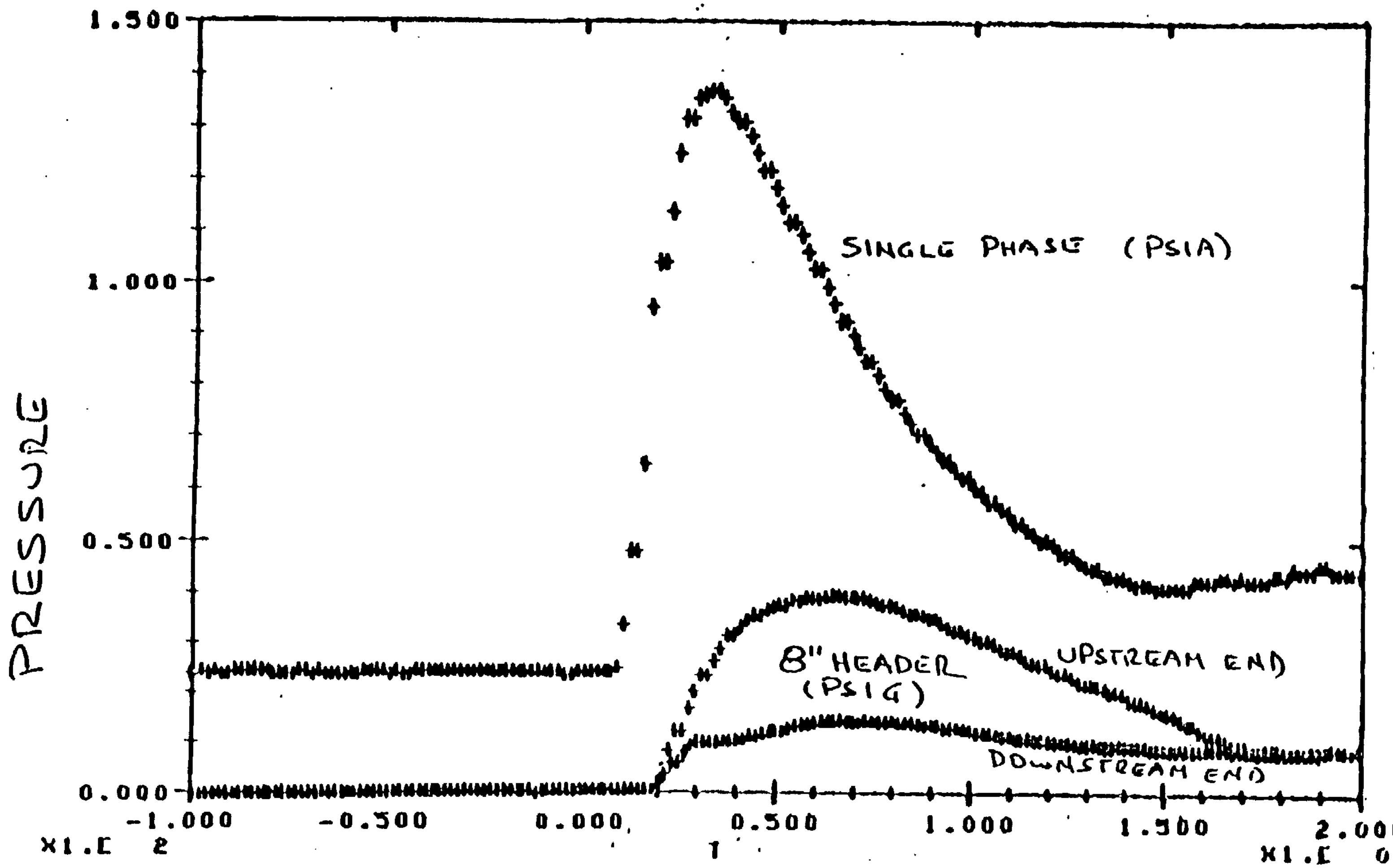

PRESSURE
1.500
1.000
0.500
0.000
-1.000
-0.500
0.000
0.500
1.000
1.500
2.001
X1.E 2
T
X1.E 0
SINGLE PHASE (PSIA)
8" HEADER
(PSIG)
UPSTREAM END
DOWNSTREAM END

FIGURE 1 B

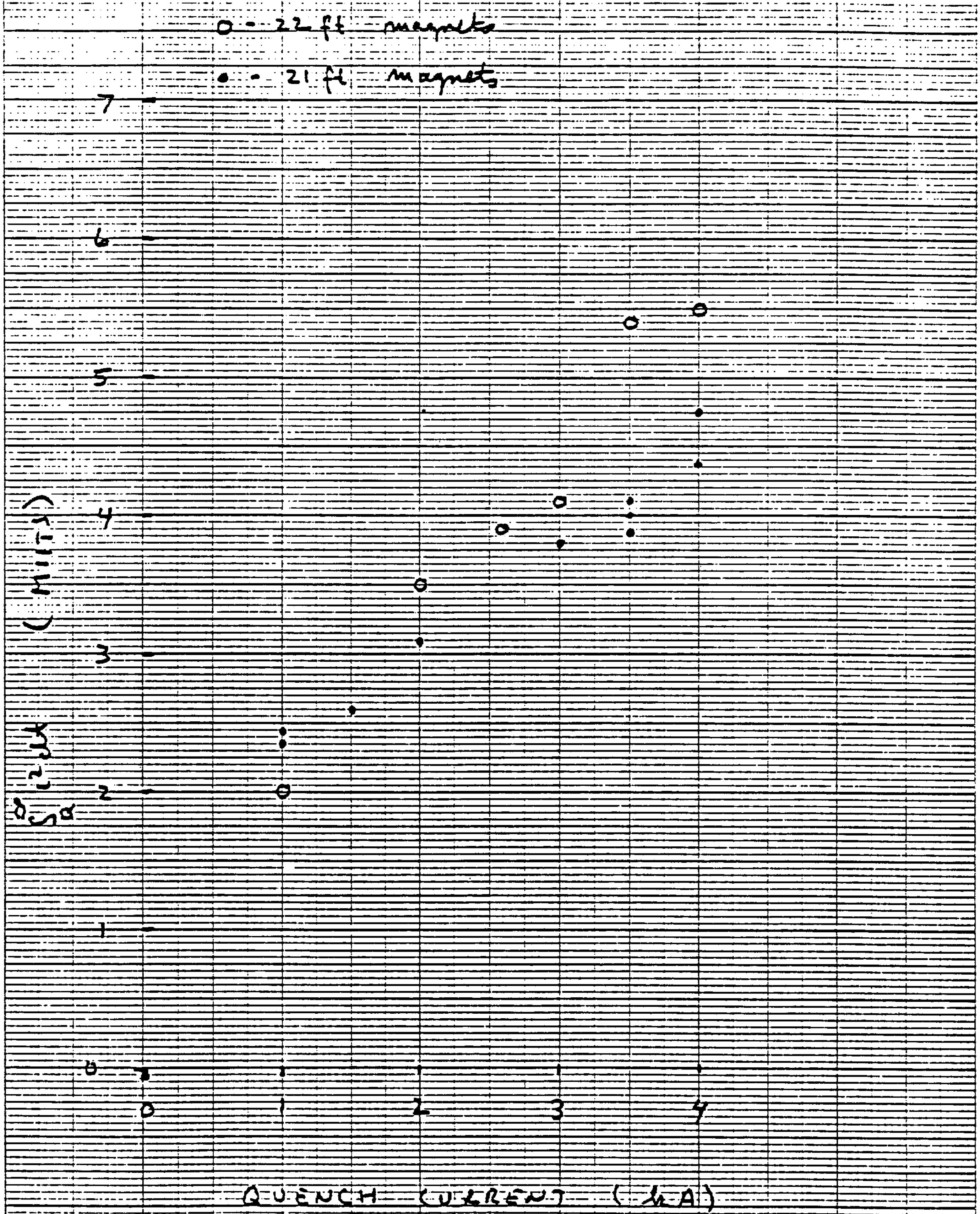
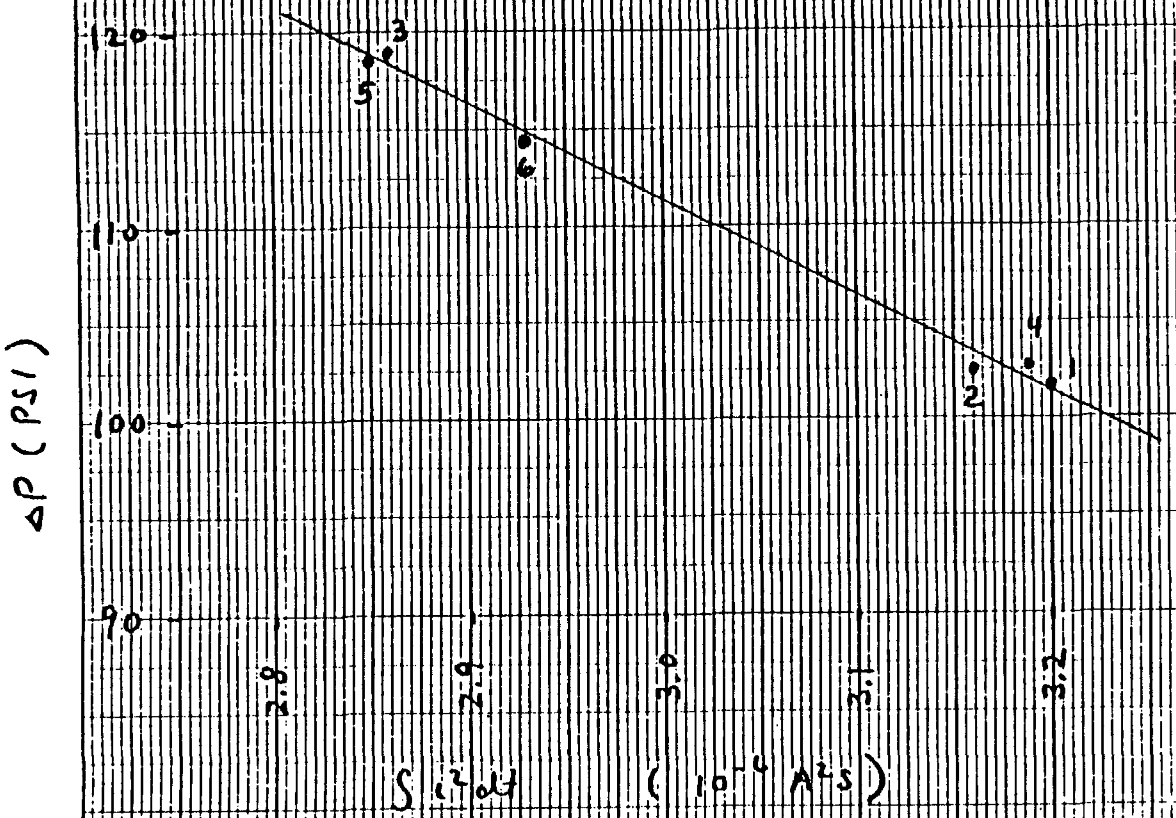


FIG 2

ALL QUENCHES AT $3889 \le I \le 3914$ A



QUENCH NO.	JOULES TO START QUENCH	JOULES IN QIM HEATER AT E (V_Q = 10V)
1.	SPONTANEOUS	439
2.	274	439
3	778	439
4	293	439
5.	911	439
6.	346	0

FIG 3

1. MTF stand 2 routinely operates at this pressure during the 4kA heater and MIIT certification of the dipoles without any indication of damage to the magnets or 1Ø bellows.
2. George Biallas has constructed a 1Ø bellow warm test fixture with a ¼" dog leg misalignment of the bellows. This fixture confirmed that the bellows withstand pressure pulses greater than 285 psi (300ms pulse). A 100 cycle, 200 psi fatigue test of the bellows also resulted in no visible damage.
3. The bore tubes of the 21' magnets have been increased from .049" wall to .060" wall. This gives an implosion extrapolation of

$$150 \left(\frac{.060}{.049}\right)^3 = 275 \text{ psi}$$

TABLE I

Single phase pressure pulse data obtained at MTF (stand 2) are listed. The dipoles were quenched every 20 minutes or longer with one of the MTF heater power supplies (nominally 430V, 4.75mF, 2Ω cable resistance) and with 2 psi of subcooling.

TB0503 (3867A)

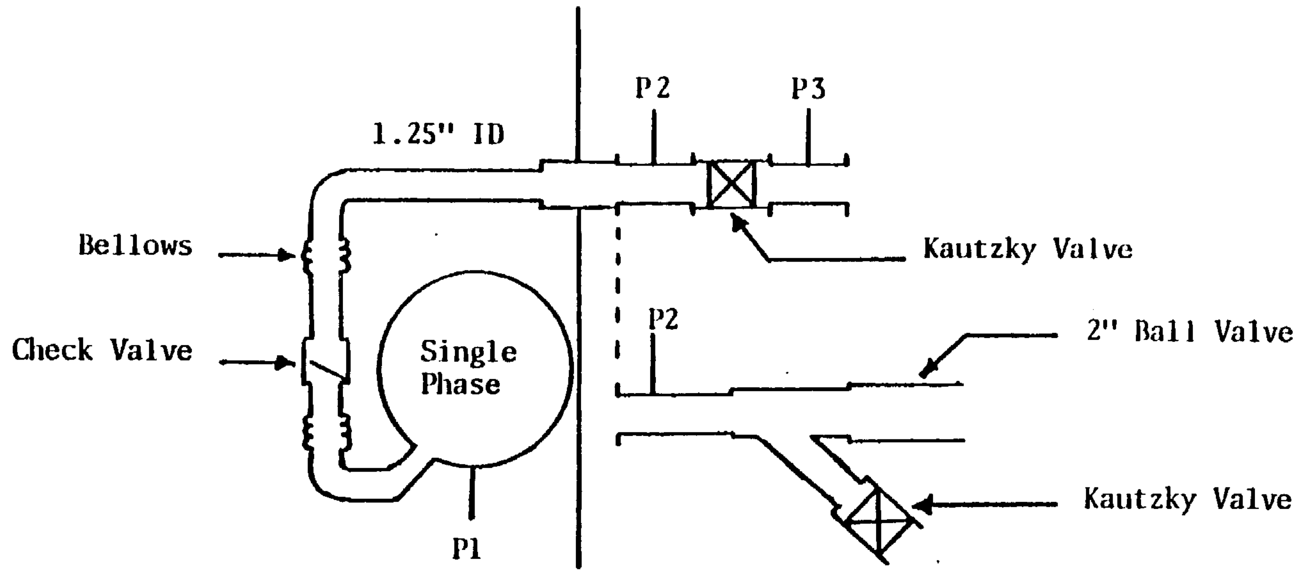
Kautzky valves vented into MTF He collection system.

Quench No.	Quench MIITS (10^6 A^2S)	1Ø ΔP (psi)	Comments
1	3.0	86	.9" ID Kautzky
2	2.8	120	" " "
3	2.8	124	" " "
4	2.8	116	1.0" ID Kautzky
5	2.9	120	" " "

TC0498 (3992A)

Kautzky valves vented into atmosphere.

Quench No.	Quench MIITS (10^6 A^2S)	1Ø ΔP (psi)	Comments
1	2.97	108.5	1.0" ID Kautzky
2	2.90	120	" " "
3	2.89	122.7	Jöstlein modification on .9" valve
4	2.82	128	Solenoid operated Jöstlein valve



Magnet	Quench Current (A)	ΔP1 (psi)	ΔP2 (psi)	ΔP3 (psi)
TC0503	3867	120[1] 115[2]	103[1] 96[2]	76.6[1] 15[2]
TC0498	4000	123[2] 99.6[3]	110[2] 39[3]	

[1]P3 venting into MTF He collection system.

[2]P3 venting into atmosphere.

[3]Kautzky valve replaced by 2" ball valve venting into air.

FIGURE 4